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CIRCULAR ECONOMY FOR PRODUCTION OF RENEWABLE FUELS AND MATERIALS FROM WASTE-TO-VALUE TECHNOLOGIES

Kristina Baziene ^{1*}, Justinas Gargasas ²

^{1*,2} Vilnius Gediminas Technical University, Department of Mechanical and Materials Engineering, Saulėtekio al. 11, LT-10223, Vilnius, Lithuania

E-mails: ^{1*} kristina.baziene@vilniustech.lt (Corresponding author); ² justinas.gargasas@vilniustech.lt;

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Abstract. The circular economy offers a sustainable framework to address escalating environmental issues, particularly waste management and resource depletion. This paper investigates the role of emerging waste-to-value technologies in supporting circular economy goals by converting waste into valuable products such as fuels, chemicals, and bioplastics. These waste-to-value technologies are evaluated for their environmental benefits, scalability, and economic viability. The study highlights how integrating such innovations can reduce reliance on virgin resources, minimize landfill use, and lower carbon emissions. Real-world industrial applications are analyzed to illustrate their scalability, economic feasibility, and environmental benefits. Ultimately, waste-to-value innovations are shown to be fundamental to realizing the goals of a circular economy, offering sustainable pathways for resource efficiency. While these technologies show strong potential, further research, policy support, and technological development are needed to overcome challenges related to economic feasibility, regulatory barriers, and large-scale implementation. The transformation of plastic waste into valuable products presents a promising approach for addressing both waste management and sustainable energy production. The waste-to-value technologies, such as pyrolysis, provide viable solutions for reducing plastic pollution and minimizing dependence on fossil fuels. However, additional advancements are necessary in areas like process efficiency, economic feasibility, and environmental impact reduction to enhance the commercial viability and scalability of these technologies. By incorporating these innovations into the larger framework of a circular economy, we can make a substantial contribution to building a more sustainable and resource-efficient future.

Keywords: circular economy; plastic recycling; pyrolysis technology; waste-to-value technologies

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1. Introduction

Waste-to-value technologies refer to innovative processes and systems designed to convert waste materials into valuable products, such as energy, fuels, chemicals, and raw materials. These technologies aim to minimize waste, reduce environmental impact, and promote sustainability by transforming what would otherwise be discarded into useful resources. Waste-to-value technologies offer several advantages. Firstly, resource recovery helps recover valuable materials and energy from waste, reducing the need for virgin resources. Secondly, environmental impact diverts waste from landfills and reducing greenhouse gas emissions, these technologies contribute to environmental sustainability. Finally, economic opportunities create jobs and stimulate economic growth by developing new industries focused on waste management and resource recovery.

The concept of a circular economy is revolutionizing how we approach the production of renewable fuels. Instead of the traditional linear model, which often leads to waste and depletion of resources, a circular approach emphasizes sustainability and efficiency. In this framework, resources are used, reused, and recycled, creating a closed-loop system that minimizes environmental impact. Ultimately, the circular economy for renewable fuel production holds immense promise. It encourages innovation, reduces environmental impact, and enhances energy security. By embracing this model, we can pave the way for a sustainable and resilient future where energy production harmonizes with ecological balance.

2. Literature Review

The circular economy model has gained considerable traction as a sustainable solution to the challenges posed by the traditional linear economy. Rather than a "take, make, dispose" approach, the circular economy advocates for designing systems that minimize waste, maximize resource efficiency, and create closed-loop processes where products and materials are reused, recycled, or repurposed. The circular economy concept highlights the significance of sustainability by encouraging the reuse, recycling, and recovery of materials to reduce waste and resource use. The principles of the circular economy have become particularly relevant in addressing the growing issue of plastic waste, which, if managed incorrectly, can lead to severe environmental and ecological consequences in relation to plastic waste. The circular economy provides innovative solutions for transforming plastic into renewable fuels.

Waste-to-value technologies facilitate the recovery of valuable materials and energy from waste, reducing reliance on virgin resources. According to Rezania et al. (2023), this contributes to a circular economy by promoting resource efficiency and sustainability (Kumar et al., 2021). These technologies play a crucial role in mitigating environmental degradation by diverting waste from landfills and reducing greenhouse gas emissions. Zhao et al. (202) emphasize that implementing waste-to-value technologies can significantly lower the carbon footprint associated with waste disposal.

The economic viability of waste-to-value technologies, which convert waste materials into valuable products such as fuels, chemicals, or energy, is critical to their widespread adoption. These technologies, including pyrolysis, gasification, and chemical recycling, hold significant potential for addressing global waste challenges while also creating economic opportunities. However, the success of these technologies depends on a variety of factors, such as investment costs, operational efficiency, market demand for byproducts, and policy incentives. The initial capital required to implement waste-to-value technologies can be high, especially for advanced processes like pyrolysis and gasification. These technologies require specialized equipment, infrastructure, and skilled personnel. According to Awogbemi et al. (2023), while the capital costs for waste-to-value facilities can be substantial, the long-term benefits, including reduced landfill use and the generation of valuable products, may outweigh the upfront investment. Additionally, operational costs must also be considered, including energy consumption, maintenance, and feedstock processing. Pyrolysis, for instance, has relatively high energy requirements, which can affect the economic feasibility of the technology if energy costs are high (Peti et al., 2025).

The revenue potential from byproducts of waste-to-value technologies plays a significant role in determining the economic viability. Pyrolysis, for example, can produce synthesis gas (syngas), oils, and solid residues, all of which can be sold or used to generate energy (Papari et al., 2021). Syngas can be used for electricity generation, while oils can be refined into transportation fuels or chemicals. The demand for these byproducts, especially in regions with limited natural resources, can significantly impact the profitability of waste-to-value processes.

However, market conditions for these byproducts can be volatile. The price of crude oil, for example, can fluctuate, affecting the market for synthetic fuels. In some cases, the revenue from byproducts may not be sufficient to cover operational costs, making the economic viability of the technology more dependent on external factors like subsidies or government support (Bocken et al., 2016).

Government policies and incentives play a crucial role in determining the economic feasibility of waste-to-value technologies. In many countries, there are growing incentives for renewable energy production, waste reduction, and the development of sustainable technologies. These can include subsidies, tax credits, or carbon pricing schemes. According to Geissdoerfer et al. (2017), policy frameworks that support waste-to-value technologies by promoting green energy, reducing waste to landfills, and encouraging sustainable development are essential to making these technologies more economically attractive.

Furthermore, regulatory standards related to waste management and environmental impact can affect the implementation and success of waste-to-value technologies. Stringent regulations on emissions, for instance, may require additional investments in pollution control equipment (Awogbemi et al., 2023), increasing the cost of implementation but also ensuring the long-term sustainability of these technologies.

The economic viability of waste-to-value technologies also depends on competition from other waste management methods, including traditional recycling, landfilling, or incineration. While WTV technologies can offer significant advantages in terms of resource recovery and waste diversion, they must compete with more established methods that may have lower upfront costs.

However, as waste-to-value technologies mature and scale up, they may benefit from economies of scale, reducing costs and improving profitability. As noted by Chow et al. (2023), advancements in technology and processes may lead to cost reductions over time, making these technologies more economically viable and accessible to a wider range of businesses and municipalities.

Plastic waste arises from the breakdown or disposal of polymer materials. When plastic products deteriorate or are discarded, they contribute to the growing problem of plastic waste. Around 4% of global oil and gas production is dedicated to plastic manufacturing. The generation of plastic waste occurs when plastic materials become outdated or unusable (Pharande & Bagwan, 2023). The widespread production and consumption of plastics play a major role in the accumulation of plastic waste. Due to their versatility and low cost, plastics are extensively used across various industries. While solar panels are pivotal in advancing renewable energy, they contribute to plastic waste due to their construction materials and challenges in recycling. Solar panels, particularly those using crystalline silicon technology, consist of various materials (Figure 1). The plastic components, especially the backsheet made of polyethylene terephthalate (PET) and polyvinyl fluoride (PVF), are essential for weatherproofing but complicate recycling efforts. These materials are not easily separable and can degrade over time, leading to environmental concerns (Xu et al., 2018).

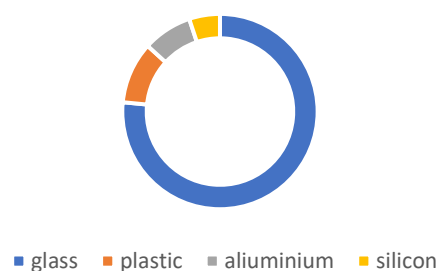


Figure 1. Solar panel composition
Source: Xu et al. (2018)

Recycling solar panels is complex due to the difficulty in separating and processing the various materials. While glass and aluminum are relatively straightforward to recycle, plastics and metals like silicon and silver require more advanced techniques. While solar panels are a cleaner energy source, their plastic components and the challenges in recycling them contribute to plastic waste. Addressing these issues requires advancements in recycling technologies and materials to ensure that the growth of renewable energy does not lead to new environmental problems (Tvaronavičienė, 2024). Various plastic manufacturing processes also lead to the creation of plastic waste (Valizadeh et al., 2024). With industrial growth and an expanding global population, the use of plastics has increased dramatically (Chang, 2023). Plastic waste is a complex mixture of different plastic polymers. Plastics are synthetic materials made from polymers, which are long chains of repeating units.

Various types of plastics exist (Figure 2), each distinguished by its distinct chemical structure and properties. Projections indicate that by 2050, global plastic waste could reach 12 billion tons (Chen et al., 2023). Pyrolysis provides a technique to convert plastic waste into oil (Papari et al., 2021).

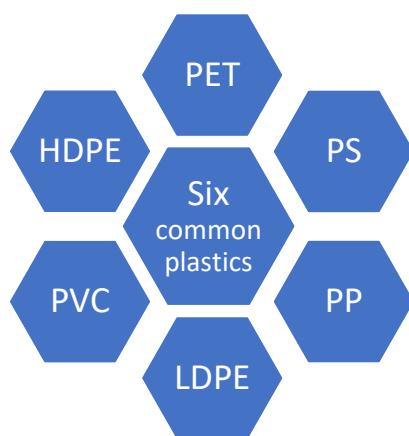


Figure 2. Six common types of plastics
Source: Chang (2023)

The prospects of using pyrolysis to convert plastic waste into liquid oil have been extensively analyzed in recent studies due to the growing concerns over plastic waste and the increasing demand for sustainable waste management solutions. Pyrolysis is a promising technology for converting plastic waste into valuable liquid fuel, addressing both the environmental issue of plastic pollution and the energy demands associated with fossil fuels.

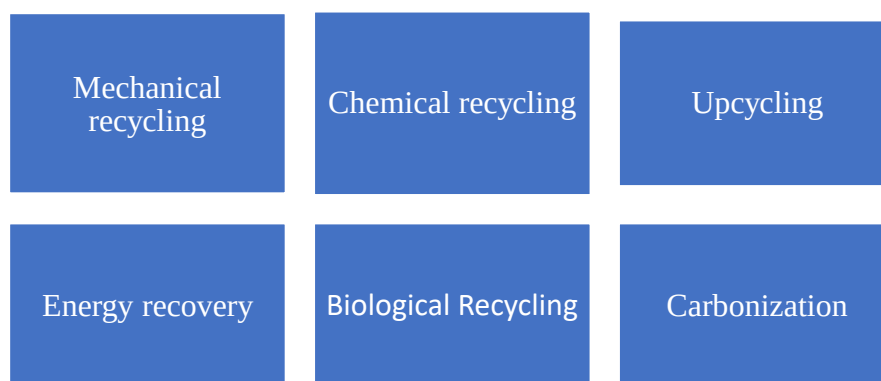
Pyrolysis involves the thermal decomposition of plastic waste in the absence of oxygen at high temperatures (typically between 300°C and 900°C). This process breaks down complex polymer chains into smaller molecules, resulting in the production of liquid oil, gases, and solid residue (char). The liquid oil produced is rich in hydrocarbons and can be further refined to be used as a substitute for fossil fuels in engines or industrial processes (Chang, 2023).

The economic feasibility of using pyrolysis on a large scale depends on factors like the cost of setting up pyrolysis plants, the efficiency of the process, and the value of the end products. Pyrolysis can be economically viable if the liquid oil produced is of high quality and can be sold at a competitive price, making it an attractive option for industries looking to capitalize on waste-to-energy solutions (Chang, 2023).

Despite its promise, the widespread adoption of pyrolysis to convert plastic waste into liquid oil faces challenges such as the need for consistent feedstock quality, economic costs, and technical limitations regarding scalability. Nevertheless, projections suggest that as technology advances and the need for sustainable waste management increases, pyrolysis could play a significant role in managing plastic waste and providing alternative energy sources (Faisan et al., 2023).

Waste-to-value technologies focus on transforming plastic waste into valuable products, thus contributing to sustainable development by reducing waste, conserving resources, and promoting a circular economy. These technologies aim to close the loop of plastic consumption by reusing or recycling plastic waste into new, useful products, including fuels, chemicals, and materials. The main waste-to-value technologies for plastic are shown in figure3.

Mechanical recycling involves physically processing plastic waste through shredding, cleaning, and re-melting to create new products. This method is effective for thermoplastics like polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET). However, it is limited by the quality degradation of plastics after multiple recycling cycles and challenges in processing contaminated materials recycling of a broader range of plastics, including those that are difficult to process mechanically.

**Figure 3.** Waste-to-Value Technologies for Plastic*Source:* Chang (2023)

Upcycling involves converting plastic waste into higher-value products. Energy recovery technologies, such as pyrolysis and gasification, convert plastic waste into energy (heat, electricity, or fuel) by thermally decomposing the plastics. These methods reduce the volume of plastic waste and generate energy, though they may emit greenhouse gases if not properly managed. Emerging biological recycling methods utilize enzymes or microorganisms to break down plastics into simpler, reusable components. While still in developmental stages, these methods offer a promising avenue for recycling complex plastics under mild conditions. Plastic carbonization involves converting plastic waste into carbon-rich materials like activated carbon, which can be used in energy storage, environmental remediation, and organic synthesis applications.

Energy recovery technologies: pyrolysis and gasification for plastic waste.

Managing energy consumption and minimizing emissions is essential for environmental sustainability throughout the waste-to-fuel process. Heat generated during pyrolysis can be recovered and reused to power the process or produce electricity. A life cycle assessment should be performed to assess the environmental benefits of the plastic waste-to-fuel process, which includes estimating the overall reduction in greenhouse gas emissions compared to the disposal of plastics in landfills or incineration, analyzing the net energy produced from the process versus the energy consumed during conversion; evaluating how much plastic waste is diverted from landfills and the circular economy benefits from recycling plastic into fuels (Alhazmi et al., 2021; Javed et al., 2025; Vlasopoulos et al., 2023).

This study explores the feasibility and potential advantages of converting waste plastics into fuel through pyrolysis within the framework of circular economy principles. By analyzing the technical, environmental, and economic dimensions of the pyrolysis process, the research evaluates its viability as both a waste management solution and an energy recovery method. The primary objectives of the study are:

- to research the application of plastic waste pyrolysis technologies within the circular economy framework, assessing its potential as a sustainable and resource-efficient technology for plastic waste management and the recovery of valuable materials.
- to assess the environmental, economic, and technical feasibility of implementing pyrolysis within circular waste management frameworks.

Through these objectives, the study aims to support the development of sustainable plastic waste management strategies and promote the use of waste to get valuable fuels.

3. Methodology of Research

The heat transfer is significant in the reactor for better breaking down of the plastics and for the height yield of the plastic oil from the plastic vapour forming inside the reactor. The heating of the reactor can be done in multiple ways (Fig. 2). The heating of the burner can be given through a burner where we can use gases like LPG, CNG, biogases, and sometimes solid fuels like wood and coal are also being used mostly in the fixed bed reactors. The reactor can also be made for electricity as a heating medium using windings created around it, and

the electricity is passed to heat it. Sometimes, solar energy can also be used to heat. The main disadvantage of this type of reactor using electricity as a medium is that it won't get the efficiency to produce enough temperature supply for producing gases from plastics. The microwave reactor is also used sometimes, but not very commonly, to produce it. Its main disadvantages are longer heating times, loss of energy, and the need for unique materials to create the special reactor. These classifications can be further broken down (see Figure 2).

The steps to investigate the conversion of plastic waste into valuable products within the context of a circular economy are investigated. The research will assess the feasibility, environmental impacts, and economic viability of various waste-to-value technologies, including mechanical recycling, chemical recycling, pyrolysis, gasification, and other advanced methods. This research was to determine how pyrolysis technologies can contribute to a sustainable, circular economy by recovering resources, reducing waste, and creating valuable materials and energy.

Economic feasibility and market considerations: an economic analysis is crucial to determine the feasibility of plastic waste-to-fuel technologies. This analysis should include capital and operational costs, which estimate the investment required for setting up the technology and maintaining operations; revenue generation, which is evaluating the revenue potential from selling the produced fuel and any co-products (e.g., chemicals, carbon black); and finally return on investment, which is analyzing the time it takes to recover the initial investment and the long-term profitability of the process.

SOLOIDWORKS was a simulation platform for designing and analyzing complex processes, including chemical reactions, heat transfer, and fluid dynamics. It simulates reactor designs requiring detailed thermodynamic, fluid dynamics, and reaction kinetics information, such as pyrolysis. The main parameter simulated is temperature. Three different temperatures were simulated for the reactor (450C, 500C, 600C), as shown in Figure 4.

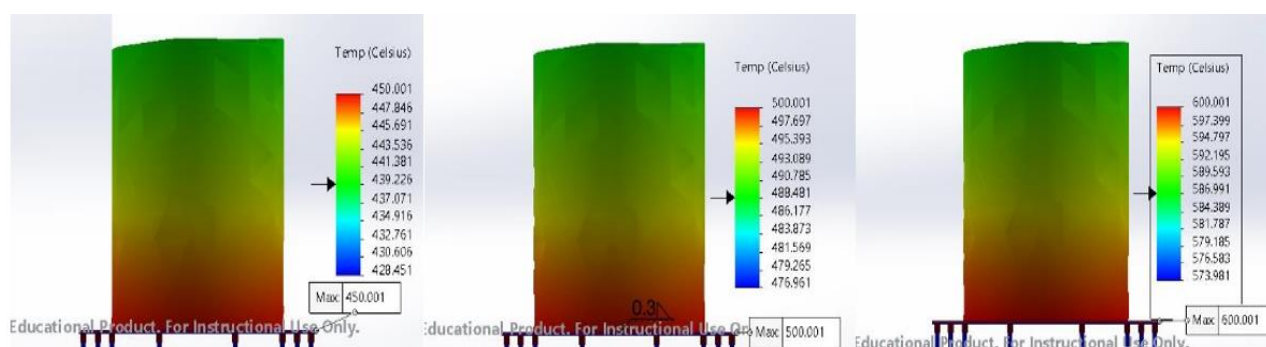


Figure 4. Heat distribution in a reactor with different heated temperatures

Source: own processing

Energy recovery technologies, including pyrolysis and gasification, are methods used to convert plastic waste into energy, such as heat, electricity, or fuel, by thermally decomposing plastics in controlled environments. These technologies are considered crucial in addressing the global plastic waste crisis, as they offer a way to reduce the volume of waste while simultaneously generating energy.

Pyrolysis is a thermal decomposition process that takes place in the absence of oxygen. When plastic waste is heated to high temperatures (usually between 350°C and 800°C), it breaks down into simpler chemical compounds. The products of pyrolysis include liquid oils, gases, and solid char. The liquid oil can be refined into valuable fuels such as diesel, gasoline, and other petrochemical products, while the gases can be used for power generation. For the simulation was used mixed plastic waste, including polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET). The chosen temperature was between 450°C and 600°C, with the exact temperature depending on the type of plastic.

4. Experimental results and discussion

Following the completion of the reactor design and its analysis in SolidWorks, the system is assumed to operate under ideal conditions with no heat loss. This assumption allows for an accurate estimation of the internal temperature retention. When the reactor is loaded with LDPE plastic waste, it reaches a thermal load of approximately 450°C. At around 400°C, the onset of pyrolysis occurs, initiating the production of pyrolytic vapours.

Table 1 above defines the plastic types used: LDPE (Low-Density Polyethylene), HDPE (High-Density Polyethylene), and PP (Polypropylene). A base plate temperature of 450°C is applied in the reactor model design. To enhance thermal retention, the base plate is strategically positioned beneath the reactor body, which helps maintain consistent heat distribution. This configuration effectively promotes gas production while minimizing wax formation during pyrolysis (Rasul et al., 2022).

The complete plastic pyrolysis system designed for converting LDPE into pyro-oil has been successfully validated through design and simulation in SolidWorks. Data obtained from simulations, along with supporting research literature, confirm that this reactor model is suitable for laboratory-scale experiments and can serve as a reliable prototype for future experimental studies.

Table 1. The parameters used for simulation with different types of plastics

Samples	a)	b)	c)
Temperature, C	450	500	600
Melting temperature, C	110	140	Depends on mixed plastics
Material (plastic)	LDPE	HDPE and PP	Mixture
Temperature of pyrolysis, C	250-380	390-500	380-550

The pyrolysis of plastic waste is a thermochemical process that breaks down polymers into smaller molecules in the absence of oxygen, converting plastic into valuable products such as liquid fuels, gases, and char. Below (Table 2) are the key aspects of plastic waste pyrolysis, categorized into technical, environmental, economic, and operational dimensions:

Table 2. The aspects of plastic waste pyrolysis process (Antelava et al., 2021)

Aspect	Description
Technical	Pyrolysis can be categorized into: - slow pyrolysis (operates at lower heating rates; higher char yield); - fast pyrolysis (rapid heating; maximizes liquid oil production); - catalytic pyrolysis (uses catalysts to enhance yield and quality of pyro-oil and reduce reaction temperature). Typically includes thermoplastics such as: low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), mixed plastics (with pre-treatment to remove PVC/PET due to harmful emissions or low oil yield). Heat transfer efficiency and residence time are critical factors in determining output quality.
Environmental	Emission Reduction: reduces plastic accumulation in landfills and oceans and can lower CO₂ emissions compared to incineration or landfilling. The pyrolysis process creates byproducts such as gas fraction (used to fuel the process itself, reducing external energy needs) and solid residue (char), which may be used as a filler or adsorbent.
Economic	Pyrolysis oil can be refined into diesel, gasoline, or chemicals. Gaseous byproducts may be reused for energy input. There are several cost considerations of pyrolysis, such as capital investment for reactor setup and control systems; operational costs including energy, labor, and feedstock preparation, and profitability depends on oil prices, plastic waste availability, and subsidies.
Operation	Feedstock preparation consists of cleaning, drying, and shredding, which are essential for efficient pyrolysis. Also, mixed plastic streams may need sorting or dechlorination (PVC removal). Process efficiency depends on consistent heating, feed rate, and oxygen exclusion. Meanwhile, energy recovery from gas fraction improves net energy balance.

The table above demonstrates how plastic waste-to-value technology (pyrolysis) is integral to the circular economy, promoting sustainability, reducing waste, and creating economic opportunities. Technologies that convert plastic waste to value (e.g., through recycling, upcycling, or energy recovery) can play a key role in a circular economy by extending the lifecycle of materials and reducing resource consumption. These technologies align with circular economy principles such as closing the material loop. In a circular economy, materials are used for as long as possible. Plastic-to-value technologies such as mechanical recycling (melting and remoulding plastics), chemical recycling (breaking polymers down into monomers or fuels,) or upcycling (converting waste into higher-value products) allow plastic waste to re-enter the economy instead of being landfilled. This reduces the need for natural mineral resources.

For instance, Sundaram et al. (2023) conducted a life cycle analysis indicating that synthetic fuels derived from plastic waste, especially when produced using renewable energy inputs, could result in 30–50% lower carbon emissions than fossil fuels. These benefits are compounded by the potential to integrate plastic-to-fuel technologies into circular economy systems, where materials are continuously reused, reducing reliance on virgin resources. The researchers emphasized the role of plastic-to-fuel conversion in promoting circularity by returning discarded plastics back into the energy cycle, thus minimizing both raw material demand and carbon emissions (Moroliya et al., 2023).

Further supporting these findings, Geyer et al. (2020) reported that approximately 8 million tons of plastic enter the oceans every year, contributing to severe marine pollution. Recycling technologies such as pyrolysis offer a promising means of reducing this flow by thermochemically breaking down plastics into usable fuels. Additionally, another group of researchers noted that the heterogeneity and contamination often present in plastic waste streams can lower the quality and yield of the resulting synthetic fuels, potentially increasing overall emissions and complicating downstream fuel purification (Hasan et al., 2025).

However, challenges remain. While plastic waste-to-fuel conversion can reduce emissions, the processes are not entirely emission-free. Abnisa et al. (2019) found that pyrolysis, a primary technology in this space, has a carbon intensity of approximately 500–700 g CO₂ /kWh. Although this is lower than many fossil fuel-based energy systems, further improvements are needed to reduce emissions from energy input and process inefficiencies. Moreover, converting plastic waste to synthetic fuels can reduce the carbon footprint of waste treatment processes by as much as 30% compared to traditional methods like incineration or landfilling (Liu et al., 2019). This reduction arises from avoided emissions associated with both plastic disposal and the extraction and refining of fossil fuels. Finally, the researchers' group estimated that converting one ton of plastic waste into synthetic fuel could offset up to 2.3 tons of CO₂ emissions that would otherwise be generated through conventional oil refining and use (Kevorkijan et al., 2023).

The plastic waste-to-value technologies for synthetic fuels present a valuable opportunity to simultaneously address two pressing environmental issues: plastic pollution and dependence on fossil fuels. This approach supports a more sustainable and circular model for both energy production and plastic waste management by transforming post-consumer plastic waste into usable energy products, particularly synthetic fuels. Each year, millions of tons of plastic end up in landfills or the natural environment, posing significant ecological risks. Converting this waste into fuel not only diverts plastic from these harmful endpoints but also offsets greenhouse gas emissions associated with conventional plastic disposal and fossil fuel use.

Waste is the primary driver behind advancing waste-to-energy technologies within the circular economy framework. Utilizing waste directly addresses sustainability challenges by ensuring a consistent and reliable year-round supply of raw materials for energy recovery. Future research should prioritize the development and optimization of valorization strategies, including improved methods for waste collection, segregation, storage, and enhancement of final product quality.

To strengthen the economic viability of waste-to-energy systems, it is essential to consider the utilization and commercialization of byproducts. However, the roles and interactions among key stakeholders remain insufficiently defined, highlighting the need for comprehensive and inclusive research. Additionally, effective policy mechanisms and incentive structures must be aligned with the latest scientific advancements to foster the

practical adoption of these technologies. Sustainability assessment models should be grounded in empirical data to minimize assumptions and uncertainties, enabling more accurate and objective evaluations of waste-to-energy systems.

Conclusions

Waste-to-value technologies represent a promising approach to addressing waste management challenges while creating valuable products and promoting sustainability. The literature indicates that while these technologies offer significant benefits, including resource recovery and reduced environmental impact, they also face challenges related to economic viability, regulatory frameworks, and public acceptance. Continued research and development and supportive policies are essential for advancing waste-to-value technologies and realizing their full potential in a circular economy.

Pyrolysis has shown to be a viable waste-to-energy technology that can not only reduce plastic waste in landfills but also provide valuable products that can displace fossil fuels, contributing to the reduction of carbon emissions. The process aligns with the principles of the circular economy, where the goal is to close the loop of product life cycles through recycling and reuse.

The adoption of plastic waste-to-value technologies faces several technical, economic, and regulatory challenges. However, with ongoing research, technological advancements, and supportive policy frameworks, these barriers can be overcome. The integration of waste-to-value technologies into the circular economy offers a sustainable path forward for managing plastic waste, reducing fossil fuel dependence, and mitigating environmental pollution.

The conversion of plastic waste to valuable products represents a promising strategy for both waste management and sustainable energy production. Technologies like pyrolysis, gasification, and chemical recycling offer solutions to reduce plastic pollution and reliance on fossil fuels. However, further advancements in process efficiency, economic feasibility, and environmental impact mitigation are needed to make these technologies commercially viable and scalable. Integrating these technologies into the broader circular economy can significantly contribute to a more sustainable and resource-efficient future.

Scientific novelty and practical value of the findings

The novelty of research into plastic waste-to-value technologies using pyrolysis lies in recent innovations that enhance efficiency, selectivity, sustainability, and integration into the circular economy. Environmental and economic performance shows high energy input and questionable environmental gains. Life cycle assessments present that carbon savings are up to half as much as landfills or incineration. Pyrolysis technologies for plastic waste are becoming for real-world circular economy integration, especially in regions lacking advanced recycling infrastructure.

Converting waste plastics into pyrolysis oil is an emerging waste-to-value approach that addresses both the growing plastic pollution crisis and the demand for alternative energy and feedstock sources. This process holds significant environmental and economic benefits by transforming low-value or non-recyclable plastic waste into a valuable liquid fuel or chemical feedstock. However, to minimize the overall carbon footprint, it is essential to carefully consider the energy sources used, enhance technological efficiency, and implement effective waste management strategies. With continued advancements in the broader adoption of renewable energy sources, pyrolysis-based plastic valorization is poised to become a more sustainable and economically attractive pathway within the circular economy framework.

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Kristina BAZIENE is the Associate Professor at Vilnius Gediminas Technical University, Faculty of Mechanics, Department of Mechanical and Materials Engineering.
ORCID ID: <https://orcid.org/0000-0002-1758-8424>

Justinas GARGASAS is the Associate Professor at Vilnius Gediminas Technical University, Faculty of Mechanics, Department of Mechanical and Materials Engineering.
ORCID ID: <https://orcid.org/0000-0001-7044-7746>

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